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Growth and Survival of Channel Catfish and Yellow Perch Exposed to Lowered Constant and Diurnally Fluctuating Dissolved Oxygen Concentrations

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16. ABSTRACT

Growth and survival were determined for duplicate lots of juvenile channel catfish (Ictalurus punctatus) and yellow perch (Perca flavescens) exposed for 69 and 67 days, respectively, to nearly constant dissolved oxygen (DO) concentrations at near air saturation (control), 6.5, 5.0, 3.5, and 2.0 mg/L. The following year juveniles of the same species were exposed to DO concentrations that gradually fluctuated diurnally at about 1.0 to 1.5 mg/L above and below the constant lowered DO levels of the previous year. At mean constant DO concentrations of 3.5 mg/L or less, channel catfish consumed less food and growth was significantly reduced (P = 0.05). Growth was not impaired by mean fluctuations of about 6.2 to 3.6 and 4.9 to 2 mg/L, but was significantly reduced at fluctuations of about 3.1 to 1.0 mg/L. Similarly, at mean constant DO concentrations near 3.5 mg/L, yellow perch consumed less food but growth was not affected; at 2.0 mg/L less food was consumed and growth was significantly reduced (P = 0.05). Growth was not affected by fluctuations of about 3.8 to 1.4 mg/L. Survival of both species was unaffected by the reduced DO exposures.

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Growth and Survival of Channel Catfish and Yellow Perch Exposed to Lowered Constant and Diurnally Fluctuating Dissolved Oxygen Concentrations

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ABSTRACT: Growth and survival were determined for duplicate lots of juvenile channel catfish (*Ictalurus punctatus*) and yellow perch (*Perca flavescens*) exposed for 69 and 67 days, respectively, to nearly constant dissolved oxygen (DO) concentrations at near air saturation (control), 6.5, 5.0, 3.5, and 2.0 mg/L. The following year juveniles of the same species were exposed to DO concentrations that gradually fluctuated diurnally at about 1.0 to 1.5 mg/L above and below the constant lowered DO levels of the previous year. At mean constant DO concentrations of 3.5 mg/L or less, channel catfish consumed less food and growth was significantly reduced ($P = 0.05$). Growth was not impaired by mean fluctuations of about 6.2 to 3.6 and 4.9 to 2 mg/L, but was significantly reduced at fluctuations of about 3.1 to 1.0 mg/L. Similarly, at mean constant DO concentrations near 3.5 mg/L, yellow perch consumed less food but growth was not affected; at 2.0 mg/L less food was consumed and growth was significantly reduced ($P = 0.05$). Growth was not affected by fluctuations of about 3.8 to 1.4 mg/L. Survival of both species was unaffected by the reduced DO exposures.

The object of this study was to determine whether gradual diurnal fluctuations in lowered dissolved oxygen (DO) concentrations affect the growth and survival of juvenile channel catfish (*Ictalurus punctatus*) and yellow perch (*Perca flavescens*). Because similar fluctuations occur in many freshwater habitats, information on the relation between fluctuating DO concentrations and the well-being of freshwater fish is important to establishing meaningful water quality criteria for use in protecting aquatic life.

Carlson et al. (1974) found channel catfish growth impaired at reduced and relatively constant mean DO concentrations between 5 and 6 mg/L and survival reduced at 4 mg/L. These fish were exposed from the embryo stage through the initial feeding stage of development. Andrews et al. (1973) reported reduced growth and food consumption of juveniles (60 g) at mean constant exposures near 5 mg/L. No literature pertinent to this study could be found on the effects of reductions in DO availability on yellow perch.

Effects of diurnal DO fluctuations on several other species and life stages have been determined. Growth of juvenile coho salmon (*Oncorhynchus kisutch*; Fisher 1963), and largemouth bass (*Micropterus salmoides*; Stewart et al. 1967), was less at widely fluctuating diurnal DO concentrations than at concentrations equal to the means of the fluctuations. Whitworth (1968) observed loss of weight in juvenile brook trout (*Salvelinus fontinalis*) exposed to diurnal DO fluctuations from near saturation to 5 mg/L. Exposure to widely fluctuating diurnal DO concentrations can also cause behavior aberrations and changes in several components of the blood of relatively larger largemouth bass, bluegills (*Lepomis macrochirus*; Bouck and Ball 1965), and rock bass (*Ambloplites rupestris*; Bouck 1972). Bouck and Ball (1965) also reported that the yellow bullhead (*Ictalurus natalis*) was unaffected at comparable DO fluctuations. Spoor (1977) reported behavioral aberrations and death of largemouth bass larvae at wide DO fluctuations. Carlson and Herman (1978) found that DO concentrations near 2.6 mg/L or above were sufficient to provide the oxygen requirements of mature black crappies (*Pomoxis nigromaculatus*) before (over-winter) and during the spawning period, and that gradual diel fluctuations about this concentration (means from about 4.1 to 1.8 mg/L) during a simulated spring water-temperature rise can cause aberrant behavior and inhibit reproduction.

Materials and Methods

Our experimental approach was to determine the survival and growth of duplicate lots of juvenile channel catfish and yellow perch at constant DO concentrations of near air saturation (control), 6.5, 5.0, 3.5, and 2.0 mg/L for more than 67 days and to compare the results with those obtained the following year with gradual diel fluctuations in DO concentrations of about 1-1.5 mg/L above and below the constant levels (Figs. 1

and 2). The apparatus used to deliver the desired DO oxygen concentrations to the test tanks has been described previously by Mount (1964), Siefert and Herman (1977), and Carlson and Herman (1978). A photoperiod of 16L:8D was used for all tests. Test temperatures used are within reported summer habitat temperature ranges for channel catfish (Biesinger et al. 1979) and yellow perch (Hokanson 1977).

In September 1976, juvenile channel catfish, obtained from the U.S. Fish and Wildlife Service hatchery at Senecaville, Ohio, were brought into the laboratory at 14°C. Temperatures were gradually raised (1-2°C each day) to the test temperature of 25°C. On 1 October, 210 fish were placed in each of 10 circular fiber glass test tanks. The aerated tanks contained 215 L of water at a depth of about 45 cm, and flow to each tank was maintained at 1.1 L/min. On 12 October, DO concentrations were gradually lowered to the constant DO test levels. The following day 10 fish were removed from each tank for use in initial weight measurements. The initial mean weight ± standard deviation was 0.8 ± 0.2 g (range, 0.3 to 1.3 g). At 2-week intervals thereafter, subsamples of 15 or more fish were removed from each tank for weight determinations and to decrease biomass. Based on the mean weight of these samples, the fish in the tanks were offered equal amounts of dry granular food (U.S. Fish and Wildlife Service diet formulations PR 11-28) at about 5% of total biomass each day. Before testing, the fish were treated prophylactically several times for 1-h periods with formalin (140 mg/L) and benzalkonium chloride (20 mg/L) for ectoparasite control. On 28 October, after testing had begun, they were treated once again with formalin because signs of parasite infections (flashing) were apparent in all tanks. Test duration was 69 days.

On 20 September 1977, channel catfish from the same source but reared at the U.S. Fish and Wildlife Service hatchery in Lake Mills, Wisconsin, were delivered to the laboratory at 13.5°C. Treatment of these fish was similar to that in the constant DO experiment. Test temperature was reached on 29 September. Testing was done in a system similar to that used in the previous experiment, except that it had been modified to provide fluctuating DO concentrations and it was located in another room. On 7 October, 105 fish were placed in each test tank. They were distributed one or two at a time to each tank and also to a sample container for use in estimating initial weight. Each tank received an equal number of fish before more were added. The initial mean weight ± standard deviation of the subsample was 1.7 ± 0.4 g (range, 0.9 to 2.4 g). On 11 October, a 71-day fluctuating DO test was initiated.

The same test systems were used for the yellow perch experiments. Juveniles were collected from Shagawa Lake near Ely, Minnesota, on 7 October 1976. Water temperature was 11°C. These fish were held in the laboratory at 14°C; between 13 and 20 December they were gradually brought to the test temperature of 20°C. On 28 December they were anesthetized with tricane methanesulfonate and 121 were placed in each tank. On 2 January 1977, the DO concentrations were gradually lowered to the constant reduced levels and the 67-day test was initiated. Subsamples (10 fish) for initial weight determinations were collected from each tank the next day. The mean weight ± standard deviation of the total initial subsample was 3.6 ± 1.1 g (range, 1.6 to 7.2 g). Subsamples of 20 fish were also removed on 25 January and 17 February. During the holding period the fish had been treated several times prophylactically for 1 h with formalin (140 mg/L), a mixture of formalin (25 mg/L) and malachite green (0.1 mg/L), or benzalkonium chloride (20 mg/L) for ectoparasite control. Flow-through oxytetracycline treatments (40 mg/L) were used during the holding period and the test when

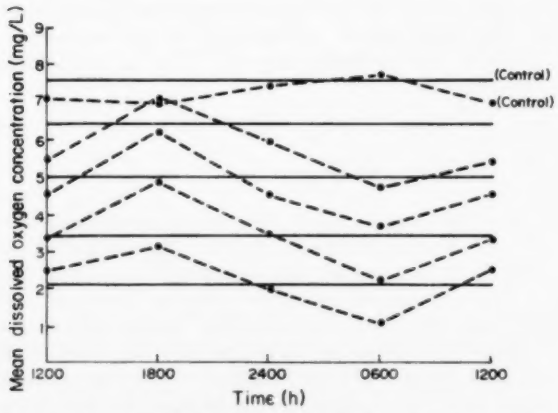

Fig. 1. Mean dissolved oxygen concentrations for the constant (solid line) and diurnally fluctuating (dashed line) treatments for the channel catfish.

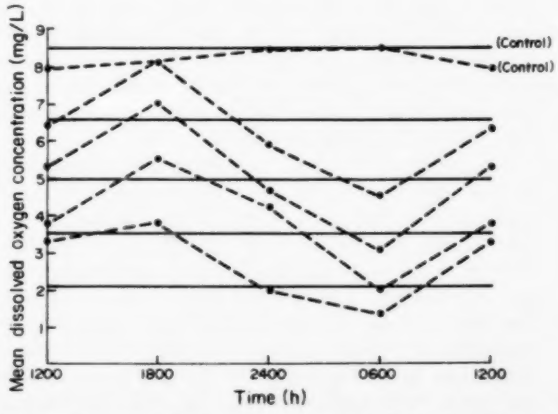

Fig. 2. Mean dissolved oxygen concentrations for the constant (solid line) and diurnally fluctuating (dashed line) treatments for the yellow perch.

deaths occurred that were not related to DO exposures. Twice a day the fish were fed frozen brine shrimp (*Artemia salina*). During testing the daily ration for the fish in each tank was 10% of the biomass per day based on the fish subsamples.

On 20 September 1977, yellow perch were captured in Pike Lake near Duluth, Minnesota, at a water temperature of 17°C for use in the experiment with diurnally fluctuating DO concentrations. These fish were gradually brought to the 20°C test-water temperature by 24 September. During this period they had been treated with formalin (140 mg/L) and oxytetracycline (40 mg/L) for ectoparasite control. On 9 January 1978, 105 fish were placed in each aerated tank. Distribution and subsampling of fish were the same in this experiment as in the fluctuating DO experiment with channel catfish. The initial mean weight ± standard deviation of the subsample was 2.9 ± 1.1 g (range, 0.8 to 5.8 g). Test duration was 70 days. Experimental conditions were similar to those in the previous yellow perch experiment with the following exceptions: diurnally fluctuating DO concentrations were used; fewer fish were used and they were not anesthetized; the food (brine shrimp) was thawed before use to get a better distribution in the tank, it was offered at 20% (increase of 100%) of biomass per day, and the amount fed was recalculated on a shorter time interval; also, the experiment was carried out in a different room.

The reported weights of the fish at the start and end of the fluctuating DO experiments are wet weights obtained after the fish had been preserved in 10% formalin solution and blotted dry. Other reported weights are either live weights or wet weights of samples that were frozen and then thawed.

The Student *t*-test with sign ignored was used to identify statistically significant differences in growth between control populations and those exposed to lower DO concentrations. A significance level of $P = 0.05$ was established.

Dissolved oxygen concentrations were determined by using the unmodified Winkler method. In the constant lowered DO experiments, measurements were alternated between duplicate tanks daily. For the diurnally fluctuating experiments, DO measurements were made daily in each tank. These measurements were used to verify readings of 10 polarographic oxygen meters, which were used in conjunction with a multichannel electronic recorder to continually monitor the DO concentrations.

Chemical characteristics of our Lake Superior water supply are nearly constant. Approximate values (milligrams per liter as $CaCO_3$) were: total alkalinity, 40; total hardness, 45; acidity, 2. Measurements of pH in the tanks during the experiment ranged from 7.0 to 7.4. Total ammonia measurements were made on at least one sample from each tank on the same day by the direct nesslerization method. For the channel catfish experiments, these measurements ranged from 0.05 to 0.19 mg/L in the constant study and from 0.07 to 0.11 in the fluctuating-oxygen study; and for yellow perch, from 0.5 to 0.9 mg/L in the constant study and from 0.04 to 0.29 in the fluctuating study. Water temperatures were continually recorded. Daily temperature measurements were also made with mercury thermometers.

Results and Discussion

At the end of the test the weight increases of the control channel catfish reared at constant reduced DO concentrations ranged from 1,025 to 1,100% (Table 1). Compared with these controls, growth was significantly reduced in only one of two tanks with mean DO concentrations near 5 mg/L. Growth at concentrations near 3.5

Table 1. Growth (means and, in parentheses, standard deviations) of juvenile channel catfish exposed for 69 days to several constant reduced dissolved oxygen concentrations at 25°C.

Dissolved oxygen concentration (mg/L)		Mean of daily temperatures (°C)	Number and final weight of fish (g)			Percentage gain from initial weight[b]
Mean[a]	Range		No.	Mean	Range	
7.7 (0.3)	7.1-8.5 (Control)	25.0 (0.2)	84	9.6 (2.8)	4.2-18.4	1,100
7.6 (0.3)	6.7-8.1 (Control)	25.0 (0.2)	79	9.0 (3.2)	3.8-20.5	1,025
6.6 (0.5)	5.5-8.0	24.9 (0.1)	82	8.3 (3.8)	2.0-18.3	937
6.3 (0.5)	5.2-7.3	25.0 (0.1)	93	9.6 (2.8)	2.4-19.3	1,100
4.9 (0.6)	3.2-6.1	25.0 (0.1)	87	8.6 (3.7)	1.0-23.6	975
5.1 (0.5)	4.0-6.5	25.0 (0.1)	84	7.6 (2.8)[c]	1.5-17.3	850
3.3 (0.4)	2.7-4.2	24.9 (0.1)	74	6.7 (1.8)[c]	4.0-12.5	737
3.5 (0.4)	2.8-4.4	24.9 (0.1)	80	5.2 (2.4)[c]	2.1-17.2	550
2.2 (0.3)	1.7-3.0	25.0 (0.2)	66	4.5 (1.1)[c]	2.6- 8.6	462
2.0 (0.2)	1.6-2.6	25.1 (0.2)	76	5.0 (1.4)[c]	1.0- 9.1	525

[a] Number of fish ranged from 34 to 35.

[b] The mean of the initial weight sample was 0.8 g (±0.2) and the range was 0.3 to 1.3 g.

[c] Significantly different from the controls (*t*-test, $P = 0.05$).

and 2.0 mg/L was significantly less. At concentrations near 5 mg/L and higher the fish appeared to feed vigorously and ate all of their daily rations; at 3.5 mg/L the fish ate most of the daily ration and at 2.0 mg/L they ate only a small portion. After feeding, the fish at 2.0 mg/L appeared stressed; increased gill ventilation was apparent and many were observed near the surface of the water. We attribute the smaller number of fish surviving in the tanks at the concentrations near 2.0 mg/L to the combined stress of the formalin treatment, ectoparasite infections (signs disappeared after treatment), and low DO concentrations. The effects on growth and food consumption were similar to those reported by Andrews et al. (1973) for larger juvenile channel catfish (initial mean weight = 60 g) which were fed ad libitum, reared at a slightly higher temperature (26.6°C), and exposed to DO concentrations near 5 and 3 mg/L. Similar effects of low DO concentrations on food consumption have been reported for several other species of juvenile fish (Herrmann et al. 1962; Stewart et al. 1967; Adelman and Smith 1970).

The percentage increase in mean weight of the control channel catfish exposed to the diurnally fluctuating DO concentrations ranged from 282 to 294% (Table 2). At the end of the test significant reductions in growth were seen only at the mean fluctuating DO concentrations of or near 1.0 to 3.1 mg/L. Fish reared at fluctuations at or near 3.6 to 6.2 and 5.2 to 7.1 mg/L attained significantly greater mean weights than did the control fish. Survival was not affected by the lowered fluctuating DO exposures.

In the constant lowered DO experiment with yellow perch, mean weight increases of control fish ranged from 155 to 216% (Table 3). Significantly less growth occurred only with the fish reared at DO concentrations near 2 mg/L; at these low concentrations the fish did not consume their daily ration of food. The fish at 3.5 mg/L consumed more food than did those at 2 mg/L, but they did not eat all of it, whereas ration consumption was complete at the higher DO concentrations. Survival was not affected by DO concentration.

In the yellow perch experiment with diurnally fluctuating DO (Table 4), mean weight increases of controls ranged from 79 to 93%. Growth and survival were similar to those of the controls at all reduced DO treatments, and food consumption was not affected.

The relative growth rates of the channel catfish and yellow perch in constant DO experiments were much greater than those in the respective fluctuating DO experiments. These differences could be due to the differences in initial weight, genetic makeup, or environmental history. Food quantity was not considered a limiting factor in growth because the amounts of food offered were relatively the same in the channel catfish experiments, whereas the yellow perch in the fluctuating experiment received at least 100% more food per gram of fish per day than did those in the constant DO experiment. However, food quality was not compared and may have differed between experiments, affecting growth. Also, the additional disturbance of the experimental fish brought about by the increased time spent by workers around the tanks during the fluctuating DO experiments may have caused the fish to expend more energy for activity and thus lessened growth.

These experiments indicate that juvenile channel catfish and yellow perch are adaptable to moderate and gradual diurnal fluctuations in DO concentration at relatively low concentrations. Growth of channel catfish

Table 2. Growth (means and, in parentheses, standard deviations) of juvenile channel catfish exposed for 71 days to several reduced diurnally fluctuating dissolved oxygen concentrations at 25°C.

Control and low and high of diel-fluctuating dissolved oxygen concentration (mg/L)				Mean of daily temperatures (°C)	Number and final weight of fish (g)			Percentage gain from initial weight[a]
0600 h		1800 h						
Mean	Range	Mean	Range		No.	Mean	Range	
7.6 (0.2)[b]	6.8-8.0	7.1 (0.3)	6.6-7.8 (Control)	25.0 (0.2)	64	6.7 (2.0)	2.6-12.7	294
7.6 (0.3)[b]	7.0-8.1	6.9 (0.4)	6.0-7.5 (Control)	25.0 (0.2)	64	6.5 (1.8)	3.6-11.0	282
5.2 (0.4)[c]	3.7-5.8	7.1 (0.7)	5.7-8.1	25.2 (0.2)	65	7.7 (2.4)[d]	3.0-16.9	352
5.2 (0.5)[c]	3.3-6.3	7.1 (0.5)	5.2-8.0	25.0 (0.2)	65	6.2 (1.9)	3.0-11.1	265
3.6 (0.5)[c]	1.8-5.0	6.2 (0.9)	4.9-7.2	25.2 (0.2)	63	7.6 (2.5)[d]	2.7-17.5	347
3.7 (0.5)[c]	2.0-4.8	6.2 (0.5)	5.1-7.2	25.1 (0.2)	64	8.0 (2.7)[d]	3.5-14.6	371
1.9 (0.5)[c]	0.5-3.4	4.8 (0.4)	3.2-6.1	25.0 (0.2)	67	6.6 (2.1)	3.1-13.0	288
2.2 (0.5)[c]	1.4-3.7	4.9 (0.4)	3.3-5.8	25.0 (0.2)	65	6.5 (1.8)	2.6-10.8	282
1.0 (0.3)[c]	0.4-1.8	3.1 (0.4)	1.5-3.9	25.0 (0.2)	66	5.8 (2.0)[d]	1.8-11.3	241
1.2 (0.2)[c]	1.6-3.5	3.1 (0.5)	1.2-3.9	25.0 (0.2)	66	5.4 (1.7)[d]	1.8- 8.8	218

[a] The mean of the initial weight sample was 1.7 (±0.4) and the range was 0.9 2.4 g.

[b] No. = 23. DO concentrations were continually monitored in these tanks only for the last 23 days of the experiment. The mean ± standard deviation and range (in parentheses) of daily Winkler measurements (N = 72) in each tank were 7.6 ± 0.2 (7.1 - 8.1) and 7.6 ± 0.2 (7.1 - 0.2).

[c] Number of fish ranged from 69 to 70.

[d] Significantly different from the controls (*t*-test, $P = 0.05$).

Table 3. Growth (means and, in parentheses, standard deviation) of juvenile yellow perch exposed for 67 days to several reduced constant dissolved oxygen concentrations at 20°C.

Dissolved oxygen concentration (mg/L)		Mean of daily	Number and final weight of fish (g)			Percentage gain from initial weight[b]
Mean[a]	Range	temperatures (°C)	No.	Mean	Range	
8.5 (0.2)	7.9-8.8 (Control)	20.1 (0.2)	56	11.4 (3.9)	4.0-20.8	216
8.4 (0.3)	7.5-8.6 (Control)	20.1 (0.2)	65	9.2 (3.2)	3.0-20.1	155
6.6 (0.4)	5.7-7.6	20.1 (0.2)	60	11.0 (3.4)	4.4-23.6	206
6.4 (0.4)	5.3-7.3	20.1 (0.2)	68	10.3 (3.3)	3.6-19.0	186
5.0 (0.6)	3.6-7.6	20.1 (0.2)	68	10.5 (3.0)	4.2-18.4	192
4.8 (0.6)	3.0-7.1	20.1 (0.2)	68	9.8 (2.8)	4.5-16.6	172
3.5 (0.5)	2.6-5.5	20.1 (0.2)	68	10.4 (3.5)	4.0-19.5	189
3.4 (0.5)	2.5-5.3	20.0 (0.2)	69	9.7 (3.2)	4.0-17.5	169
2.1 (0.3)	1.2-3.5	20.1 (0.3)	52	8.1 (2.3)[c]	4.1-14.0	125
2.0 (0.2)	1.6-3.3	20.2 (0.2)	69	8.4 (2.4)[c]	3.6-15.9	133

[a] Number of fish ranged from 33 to 34.
[b] The mean of the initial weight sample was 3.6 (±1.1) and the range was 1.6 7.2 g.
[c] Significantly different from the controls (*t*-test, $P = 0.05$).

was significantly reduced at nearly constant mean DO concentrations of about 3.5 mg/L or less and at mean diurnal fluctuations near 3.1 to 1.0 mg/L, but was not impaired at mean diurnal fluctuations near 4.9 to 2.0 mg/L. Yellow perch were more tolerant of lower DO concentrations, and growth was significantly reduced by constant mean concentrations near 2.0 mg/L, but was not affected by mean diurnal fluctuations of 3.8 to 1.4 mg/L.

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Table 4. Growth (means and, in parentheses, standard deviation) of juvenile yellow perch exposed for 70 days to several reduced diurnally fluctuating dissolved oxygen concentrations at 20°C.

Control and low and high of diel-fluctuating dissolved oxygen concentration (mg/L)				Mean of daily	Number and final weight of fish (g)			Percentage gain from initial weight[c]
0600 h		1800 h		temperatures				
Mean[a]	Range	Mean[a]	Range	(°C)[b]	No.	Mean	Range	
8.4 (0.2)	7.8-9.1	8.2 (0.4)	7.0-9.0 (Control)	20.1 (0.2)	58	5.6 (1.3)	3.3- 9.6	93
8.5 (0.2)	7.9-9.0	8.0 (0.5)	6.8-9.0 (Control)	20.1 (0.2)	62	5.2 (1.3)	3.0- 9.2	79
4.5 (0.6)	3.5-7.2	8.2 (0.6)	7.0-9.5	20.1 (0.2)	60	5.4 (1.3)	3.1- 8.8	86
4.5 (0.6)	3.5-6.8	8.0 (0.6)	6.8-9.3	20.0 (0.1)	61	5.6 (1.6)	2.2-10.7	93
3.1 (0.6)	2.3-5.6	7.0 (0.5)	5.6-8.0	20.0 (0.1)	61	5.5 (1.3)	2.7-10.0	90
3.2 (0.5)	2.1-5.5	7.1 (0.5)	5.8-8.4	20.0 (0.1)	61	5.7 (1.4)	3.3- 9.2	96
2.0 (0.4)	1.4-3.6	5.4 (0.5)	4.0-7.0	20.0 (0.1)	65	5.5 (1.4)	3.3- 9.9	90
2.0 (0.5)	0.9-3.8	5.6 (0.5)	4.2-7.3	20.0 (0.2)	60	5.6 (1.2)	2.9- 8.4	93
1.4 (0.2)	0.7-2.4	3.8 (0.5)	2.5-5.0	20.0 (0.1)	62	5.3 (1.5)	2.3- 9.9	83
1.4 (0.2)	1.1-2.3	3.8 (0.4)	2.8-4.5	20.0 (0.1)	62	5.5 (1.6)	2.5-10.5	90

[a] Number of fish ranged from 67 to 70.
[b] No. = 71; includes temperatures for day before DO experimentation started.
[c] The mean of the initial weight sample was 2.9 (± 1.1) and the range was 0.8 - 5.8 g.

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